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# HIGH-PERFORMANCE, HIGH-EFFICIENCY GHP DEVELOPMENT

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## ABSTRACT

The gas engine-driven heat pump air conditioner (GHP) has outdoor compressors powered by a gas engine. This is a gas air-conditioning system that heats and cools by means of heat-pump operation. Tokyo Gas, Osaka Gas, Toho Gas, and the GHP manufacturers Aisin Seiki, Sanyo Electric and Yanmar Energy Systems have jointly worked on the development of high efficiency GHP. In this paper we will describe the technologies used for improved efficiency, and we will introduce the performance of our newly developed GHP.

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# Paper

## 2.1 What is GHP

The gas engine-driven heat pump air conditioner (GHP) has outdoor compressors powered by a gas engine. This is a gas air-conditioning system that heats and cools by means of heat-pump operation. The GHP, in contrast to an electric type of heat pump air conditioner (EHP) that drives the compressor by means of an electric motor, drives the compressor by means of a gas engine. Thus it follows that the GHP has the advantage of using very little electrical power as compared to EHP. The refrigeration cycles for both the GHP and EHP are based on the same fundamentals (see Figure 1),.However there are advantages such as a significantly reduced defrost operation because, it's possible for the GHP to utilize the engine exhaust heat during heating.

Since the introduction of GHP models for sale in Japan in 1987, they have been recognized as having advantages such as savings in electrical power consumption as well as low operating costs, and advancements continue to the present day. In this paper we will introduce a high-performance, high-efficiency GHP jointly developed by Tokyo Gas, Osaka Gas, Toho Gas and the GHP manufacturers Aisin Seiki, Sanyo Electric and Yanmar Energy Systems.

## 2.2 Development Objectives

### 2.2.1 Previous efficiencies

The trend in GHP efficiencies over the years is presented in Figure 2. It stands to reason that the development of high-efficiency GHP has steadily progressed since the product entered the market. However, with the current energy conservation trend, and from the viewpoint of counteracting global warming through the reduction of CO2 emissions, there is a pressing need to further improve GHP efficiency. Accordingly, since 2008 we have worked on the development of a high-efficiency GHP.

### 2.2.2 Performance evaluation index

As is shown in Figure 2, the coefficient of performance (COP) was used as an performance evaluation index in the past (up until 2006). Therefore, for prior high-efficiency GHP development, efforts to increase the COP rating came to be the focus of our work.

Here, the COP is a numerical value that expresses the energy-consumption efficiency during a time of rated operation. It is an index that does not take into account partial-load operation. However, under climatic conditions such as those found in Japan, it often occurs during the course of a year that the operation time under partial load is longer than that under the rated load. Thus it can be said that the COP does not provide an appropriate performance evaluation index for the way the product is actually used.

Alternatively, the method of computing the annual performance factor (APF) is stipulated by the JIS, and because the value expresses the energy-consumption efficiency for the whole year it can be deemed an efficiency benchmark that accounts for the frequent occurrences of partial-load operation throughout the year. Because the APF is a performance evaluation index that more accurately reflects the actual usage of the product, the APF has recently (since 2007) come into the mainstream as an expression of the efficiency of multi-type package air conditioner.

Furthermore, the energy consumed by the GHP is comprised of both fuel gas (primary energy) and electric power (secondary energy). Because the energy consumed by the EHP is solely electric, in order to make a fair comparison between them it is necessary to convert the APF to a primary energy. In Rationalization in Energy Use Law in Japan, it is provided to the conversion of the electric power of 1kW into primary energy 9760kJ, so in our development that value was used for all primary energy amount conversions. This calculated APF, or APFp (Annual Performance Factor primary), was used as the performance evaluation index as well as to set our development objectives.

2.2.3 Efficiency Targets

The APFp for the prior GHP was approximately 1.90, but for our development we set an efficiency target of an APFp of 2.05 or greater. This was the highest efficiency among all multi-type package air conditioner; thus the target was set very high.

**2.3 Initiatives for efficiency improvement**

The efficiency of GHP is determined by the product of the gas-engine drive source’s efficiency and the refrigeration cycle efficiency. Accordingly, for our development we decided to work on both aspects of the issue: efficiency improvements for the gas engine as well as the refrigeration cycle.

As previously discussed, we focused on the APFp as the efficiency during the partial-load operation. It was particularly important to improve the efficiency during 50% load in order to improve the APFp. Consequently, it was important for us to incorporate a number of technologies that improved the partial-load operation efficiency. There are differences in the adopted technologies, depending on the GHP manufacturer, but the key technical details are explained below.

2.3.1 Gas engine efficiency improvements

2.3.1.1 Downsizing the gas engine

In order for an engine to intake combustion air into the combustion chamber, as well as to expel the exhaust gases, a pumping motion is used. A portion of the engine output power is used for this pumping motion, and that portion is seen as a loss from the net power of the engine. This is referred to as the “pumping loss.” A throttle valve is used to regulate the amount of intake air, which controls the output power of the gas engine, but under conditions in which the throttle is constricted, the throttle valve resists the incoming air and the efficiency is reduced.

Regarding the case where identical output power is obtained from engines having different displacements, because there is no power margin in the smaller-displacement engine, the throttle tends to stay open, resulting in a lower degree of pumping loss. On the other hand, because there is an output power margin for the larger displacement engine there is a tendency for the throttle to be constricted and the pumping loss to increase. Because this difference in pumping loss becomes apparent in the engine efficiencies, generally speaking, for cases in which the identical output power is obtained from engines having various displacements, the engines with smaller displacements will have lower fuel consumption.

For the gas engines used for the GHP, the engine displacement corresponding to the air-conditioning capacity is selected. However, because general-purpose engines are diverted to this application there are cases in which a small amount of excess power will be provided. Focusing on that fact in our product development, in order to optimize the engine output we sought improved efficiency by reducing the engine displacement (downsizing).

2.3.1.2 Slowing down the gas engine

As shown in Figure 5, in the RPM range of gas engines for the GHP, there is a basic tendency for the efficiency of an engine to improve as it operates at higher torque. A typical GHP is shown in Figure 6, showing that the rotational motion of the gas engine is output to a pulley, whereupon a resin belt transmits the power to the compressor pulley, rotating the compressor. Because of this arrangement it is possible to increase the rotational torque by increasing the diameter of the engine pulley.

Another basic characteristic of GHP is that the air-conditioning power output is controlled by adjusting the engine RPM up or down. Because the air-conditioning power output is proportional to the quantity [engine RPM x torque] when only the torque is increased, it isn’t possible to run at conventional low-load conditions. Therefore, for identical air-conditioning output it is necessary to reduce the engine RPM in the case of high-torque operation. For conventional GHP, the engine RPM is also reduced to be near the limit, and even lower engine-rotation speeds will give rise to issues such as vibration and durability. These are challenges we are undertaking.

In our development, when the engine pulley diameter was increased it was possible to operate at high torque by simultaneously expanding the engine range on the low-RPM side. In this way the engine efficiency was improved and an improvement in GHP efficiency was achieved.

### 2.3.2 Efficiency improvements of the refrigeration cycle

The outdoor air heat exchanger is an important component that influences the efficiency of the refrigeration cycle. During cooling operation we can see that the outdoor air heat exchanger functions as a condenser, with the high-pressure gas refrigerant from the compressor being cooled by the outside air and thereby condensing into a liquid refrigerant. We worked on the performance improvement of the outdoor air heat exchanger with the objective of improving the efficiency of the refrigeration cycle.

#### 2.3.2.1 Optimizing the path of the outdoor air heat exchanger refrigerant

The heat exchanger performance is dependent on the heat-transfer coefficient on the refrigerant side. Here the heat-transfer coefficient is expressed as a function of the Reynolds number, as shown in the equations below. Because the Reynolds number is proportional to the flow rate, it is possible to improve the performance of the heat exchanger by increasing the flow rate of the refrigerant. On the other hand, when the flow rate is increased there is also an increase in pressure loss. Because there is an increased pressure loss when the flow rate of the gaseous portion is increased, the average condensation temperature is decreased and the performance of the heat exchanger is degraded. Moreover, the pressure loss decreases as the refrigerant density increases. Therefore, for the gas portion of the flow, the pressure loss increases; for the liquid portion, the pressure loss decreases.

$$h = Nuk/L$$
$$Nu = 0.664Re^{1/2}Pr^{1/3}\ (Re<10^5)$$
$$Re = UL/v$$

| | |
|---|---|
| h: heat-transfer coefficient [W/(m2K)] | Nu: Nusselt number |
| k: fluid thermal conductivity [W/(mK)] | Re: Reynolds number |
| U: flow rate [m/s] | Pr: Prandtl number |
| L: length in flow direction [m] | v: kinematic viscosity [m2/s] |

For conventional outdoor air heat exchangers, as shown in the upper part of Figure 7, the gas refrigerant that is compressed in the compressor diverges at the entrance to the heat exchanger, where there are multiple rows of pipes and flows are in parallel. At the exit of the heat exchanger, the piping arrangement allows the streams of the refrigerant, now liquid, to recombine. As shown in the lower portion of Figure 7, the structure of our developed system separates the liquid and gas portions of the flow. For the gas portion the flow path is increased over conventional arrangements, resulting in reduced pressure loss. On the liquid side, where the pressure loss is small, the flow path is reduced; such an arrangement yields an increased flow rate. Thus there is both a reduction in pressure loss and an increase in the heat-transfer coefficient, resulting in an improvement in the heat exchanger performance.

2.3.2.2 Modification of the outdoor air heat exchanger fin pitch

GHP outdoor air heat exchangers are of the direct-flow type, with aluminum plate fins attached to copper refrigerant pipes as shown in Figure 8. The spacing alignment of these aluminum fins has been made narrower than in the prior versions, and consequently it has become possible to increase the number of fins without increasing the size of the heat exchanger. Accordingly, the heat transmission area was increased and the heat exchanger performance was improved.

## 2.4 New model performance

2.4.1 Efficiency

There is a lineup of newly developed GHPs with cooling capacities ranging from 45 kW to 85 kW, available for sale since April 2011. By combining the technologies introduced in this paper, the efficiency targets have been reached, with the frontrunners attaining an APFp of 2.05. Each model has an APFp of 2.00 or greater as shown in Figure 9. An APFp of 2.05 is the highest efficiency in the market segment for multi-type air conditioners (regardless of gas or electric type).

2.4.2 Environmental performance

Accompanying the improved efficiency, environmental performance is also improved. An objective comparison of the environmental performance as compared to a prior model is given in Figure 10. For the 45 kW model having the greatest efficiency improvement, the year-long primary energy consumption amount is reduced by 19%, and the yearly $CO_2$ discharge amount is reduced by 20%.

### 2.4.3 Installation

More than 25 years have elapsed since the first GHP units were sold, and there is increased demand to replace the old models that have outlived the service life. As a result of this demand for updating, there is a minimum requirement that the installation area should be equal to or less than that of the old models. From that standpoint it was possible to provide all models of the newly developed GHP with footprints equal to or less than those of the prior models.

## 2.5 Summary

### 2.5.1 Initiatives

Developments to improve the efficiency were implemented, with a target GHP efficiency of APFp 2.05 or greater.

The following technical developments were implemented in order to improve the efficiency:

- Gas engine displacement reduction
- Gas engine operation at high torque and low RPM
- Outdoor air heat exchanger flow path optimization
- Outdoor air heat exchanger fin pitch changes

### 2.5.2 Results

- For models with cooling capacities between 45 kW and 85 kW, the frontrunner has an APFp of 2.05, and all the models have attained APFp values of 2.00 or greater.
- For the 45 kW model having the most improved efficiency, a comparison to existing models indicates that reductions of primary energy up to 19% and of $CO_2$ up to 20% are possible.
- The new model GHP units have installation areas less than or equal to those of the prior models.

## 3. LIST OF FIGURES

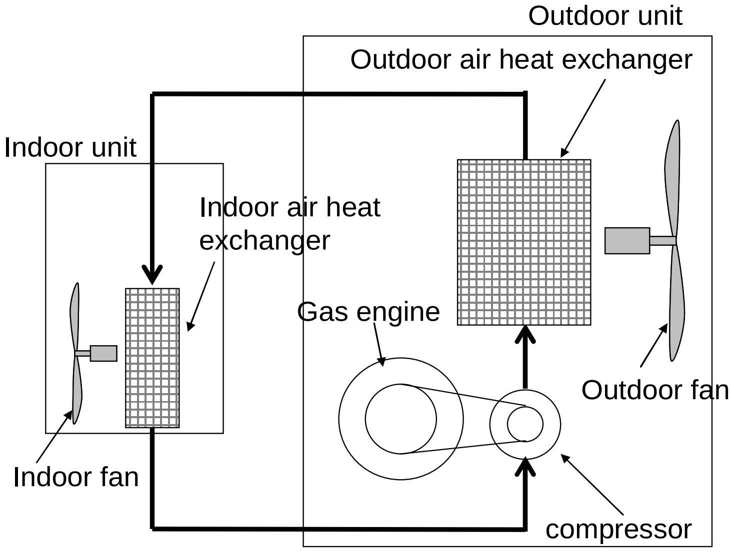


Figure 1: GHP configuration

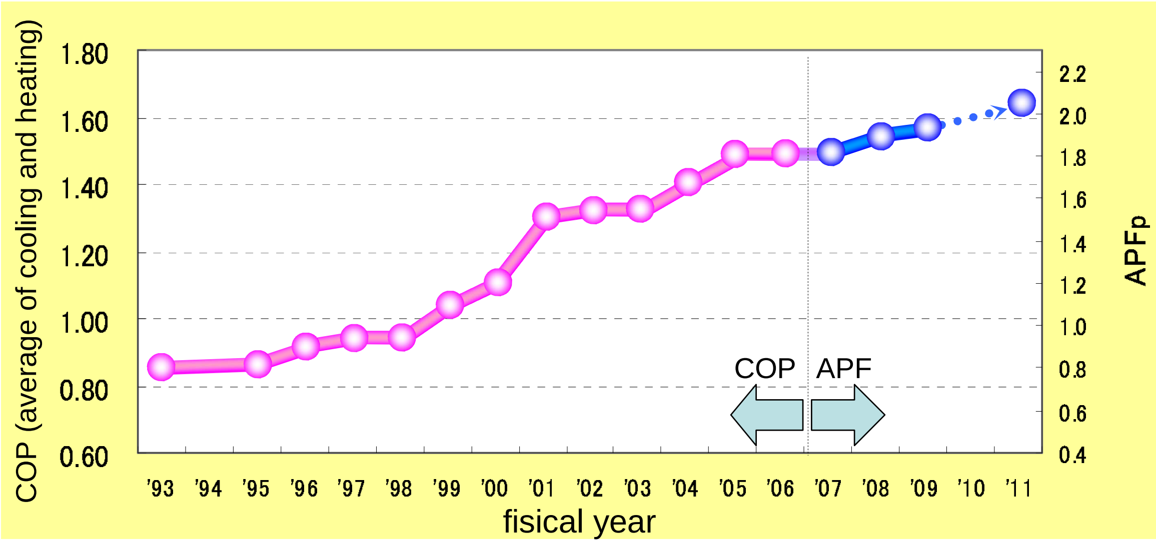


Figure 2: GHP efficiency trend

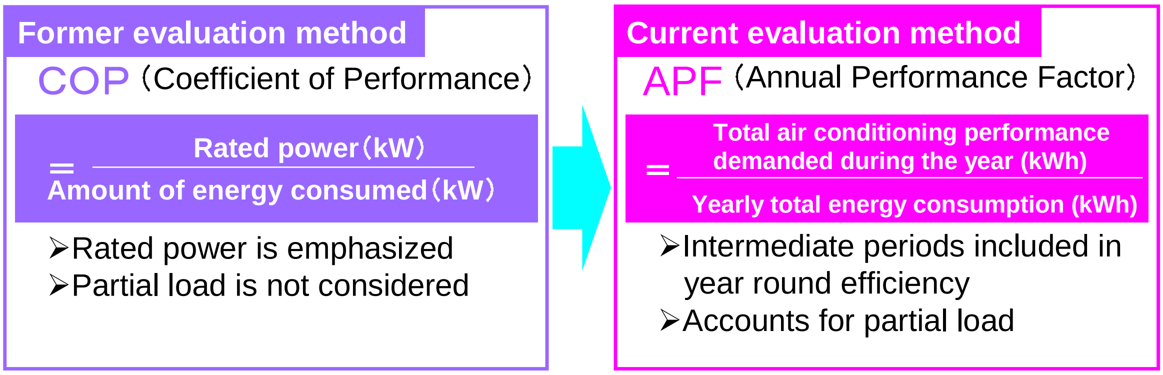


Figure 3: Efficiency indicators

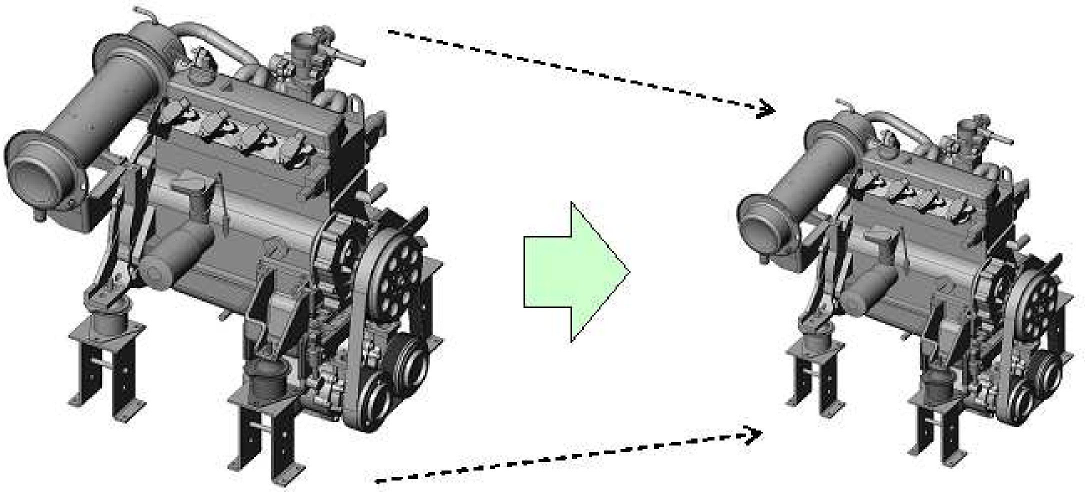

Figure 4: Engine downsizing

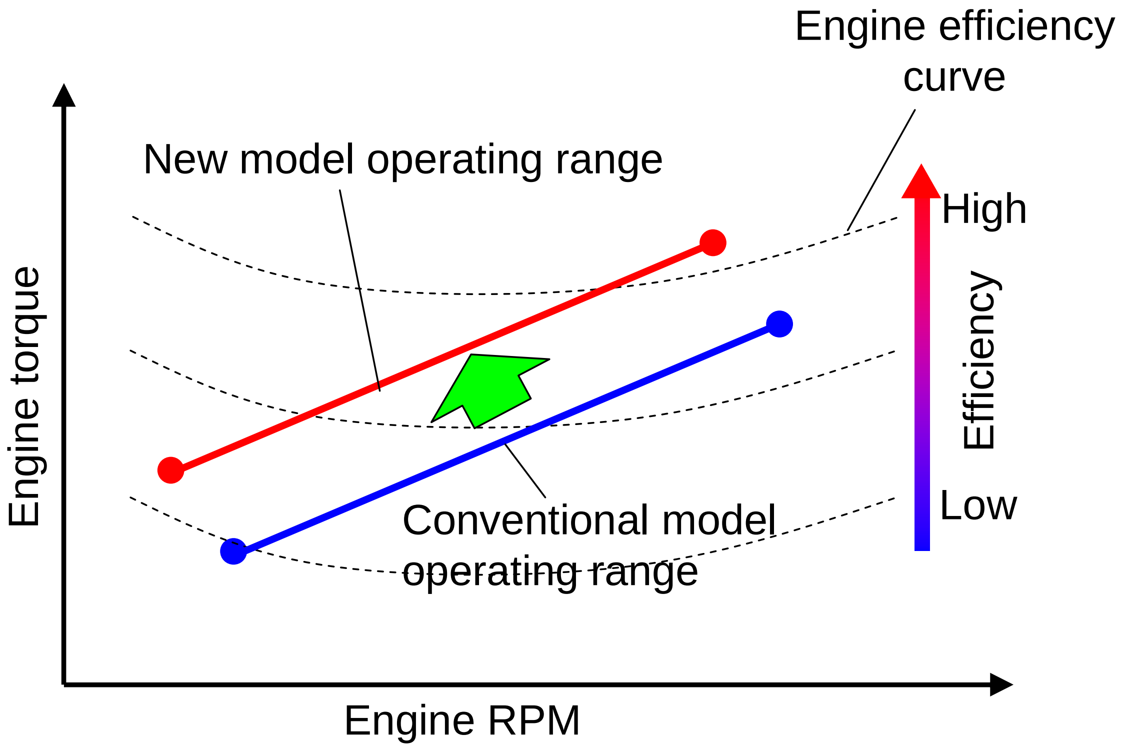

Figure 5: Engine efficiency characteristics

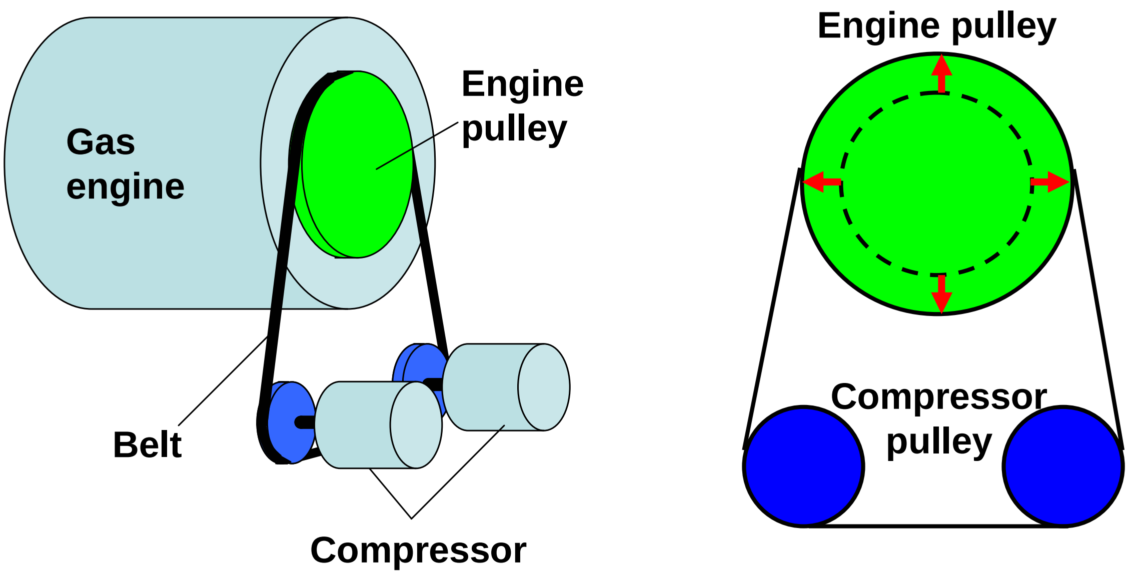

Figure 6: Rotational power transmission schematic diagram

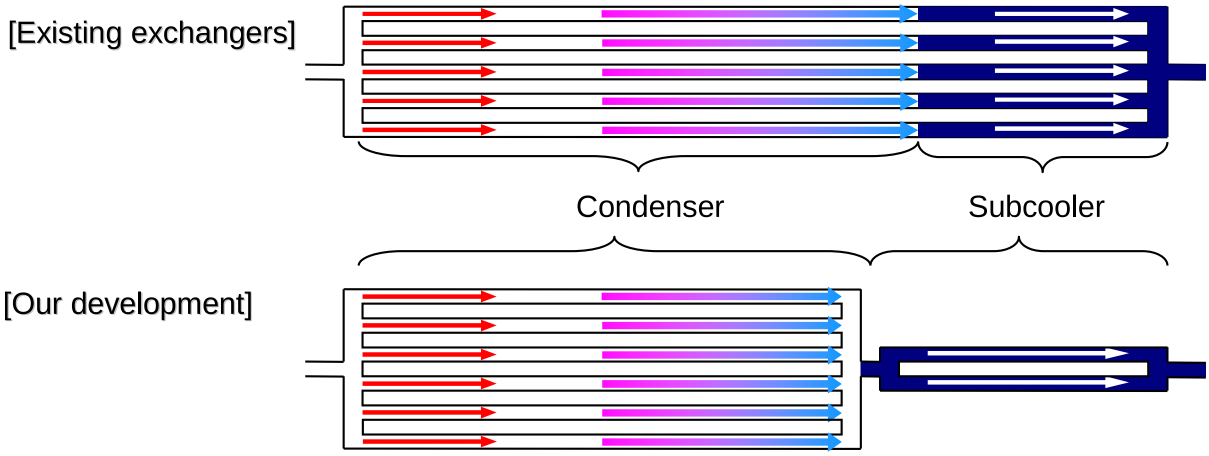


Figure 7: Outdoor air heat exchanger refrigerant flow path

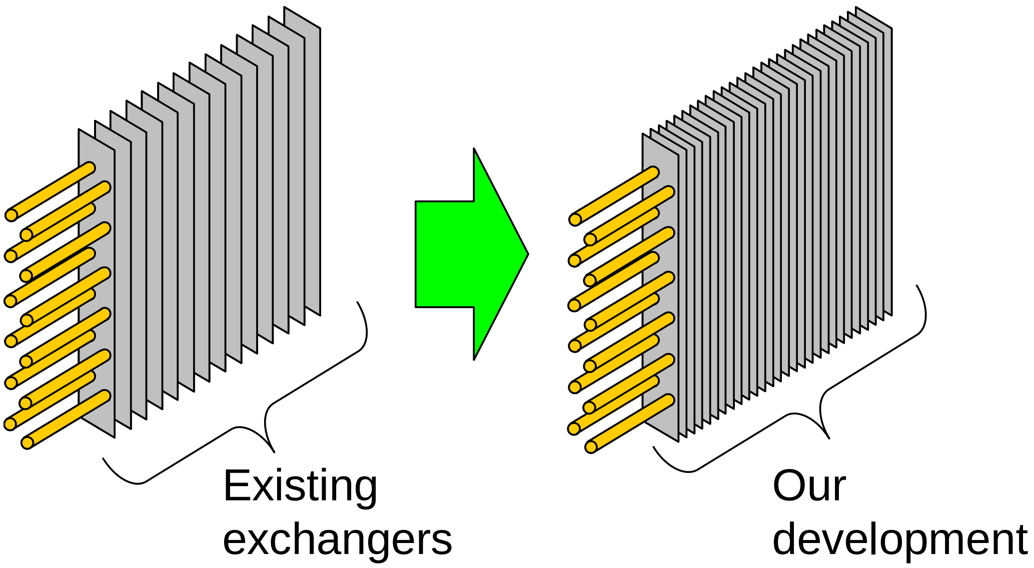


Figure 8: Heat exchanger fin pitch

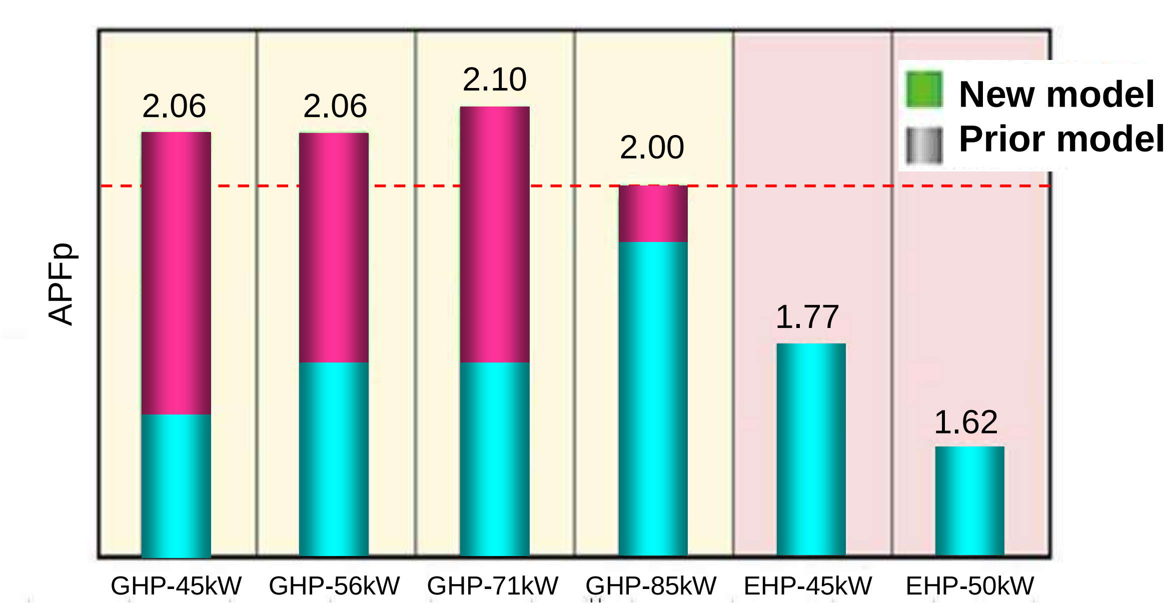

Figure 9: New model GHP efficiencies

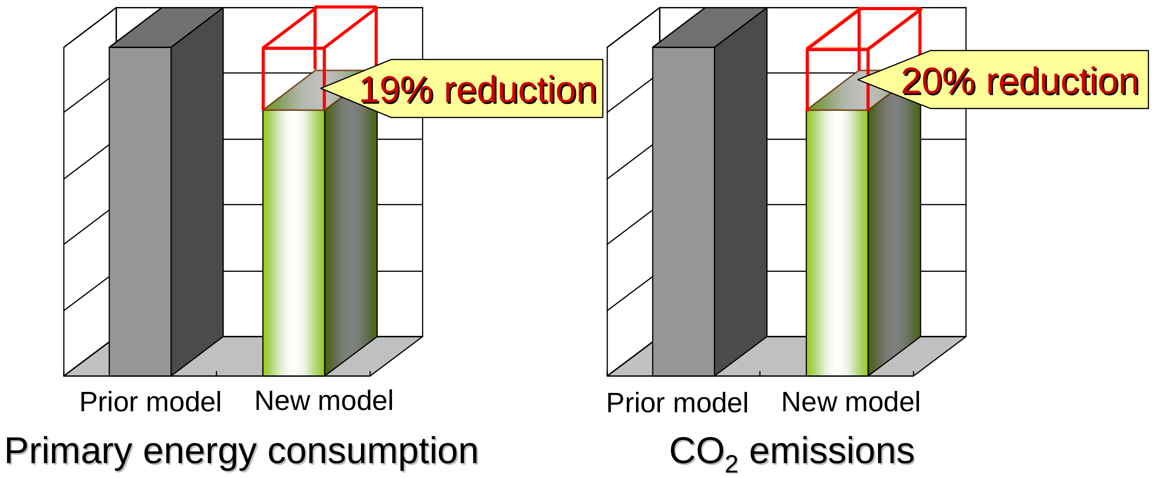


Figure 10: Environmental performances of the new model GHP